CHAPTER 4

DESIGN OF DEWATERING, PRESSURE RELIEF, AND GROUNDWATER CONTROL SYSTEMS

4-1. Analysis of groundwater flow.

a. Design of a dewatering and pressure relief or groundwater control system first requires determination of the type of groundwater flow (artesian, gravity, or combined) to be expected and of the type of system that will be required. Also, a complete picture of the groundwater and the subsurface condition is necessary. Then the number, size, spacing, and penetration of wellpoints or wells and the rate at which the water must be removed to achieve the required groundwater lowering or pressure relief must be determined.

b. In the analysis of any dewatering system, the source of seepage must be determined and the boundaries and seepage flow characteristics of geologic and soil formations at and adjacent to the site must be generalized into a form that can be analyzed. In some cases, the dewatering system and soil and groundwater flow conditions can be generalized into rather simple configurations. For example, the source of seepage can be reduced to a line or circle; the aquifer to a homogeneous, isotropic formation of uniform thickness; and the dewatering system to one or two parallel lines or circle of wells or wellpoints. Analysis of these conditions can generally be made by means of mathematical formulas for flow of groundwater. Complicated configurations of wells, sources of seepage, and soil formations can, in most cases, be solved or at least approximated by means of flow nets, electrical analogy models, mathematical formulas, numerical techniques, or a combination of these methods.

c. Any analysis, either mathematical, flow net, or electrical analogy, is not better than the validity of the formation boundaries and characteristics used in the analysis. The solution obtained, regardless of the rigor or precision of the analysis, will be representative of actual behavior only if the problem situation and boundary conditions are adequately represented. An approximate solution to the right problem is far more desirable than a precise solution to the wrong problem. The importance of formulating correct groundwater flow and boundary conditions, as presented in chapter 3, cannot be emphasized too strongly.

d. Methods for dewatering and pressure relief and their suitability for various types of excavations and soil conditions were described in chapter 2. The investigation of factors relating to groundwater flow and to design of dewatering systems has been discussed in chapter 3. Mathematical, graphical, and electroanalogous methods of analyzing seepage flow through generalized soil conditions and boundaries to various types of dewatering or pressure relief systems are presented in paragraphs 4-2, 4-3, and 4-4.

e. Other factors that have a bearing on the actual design of dewatering, permanent drainage, and surface-water control systems are considered in this chapter.

f. The formulas and flow net procedures presented in paragraphs 4-2, 4-3, and 4-4 and figures 4-1 through 4-23 are for a steady state of groundwater flow. During initial stages of dewatering an excavation, water is removed from storage and the rate of flow is larger than required to maintain the specified drawdown. Therefore, initial pumping rates will probably be about 30 percent larger than computed values.

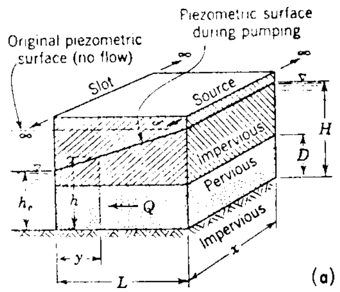
g. Examples of design for dewatering and pressure relief systems are given in appendix D.

4-2. Mathematical and model analyses.

a. *General.*

(1) *Design.* Design of a dewatering system requires the determination of the number, size, spacing, and penetration of wells or wellpoints and the rate at which water must be removed from the pervious strata to achieve the required groundwater lowering or pressure relief. The size and capacity of pumps and collectors also depend on the required discharge and drawdown. The fundamental relations between well and wellpoint discharge and corresponding drawdown are presented in paragraphs 4-2, 4-3, and 4-4. The equations presented assume that the flow is laminar, the pervious stratum is homogeneous and isotropic, the water draining into the system is pumped out at a constant rate, and flow conditions have stabilized. Procedures for transferring an anisotropic aquifer, with respect to permeability, to an isotropic section are presented in appendix E.

(2) *Equations for flow and dmwdown to drainage slots and wells.* The equations referenced in paragraphs 4-2, 4-3, and 4-4 are in two groups: flow and drawdown to slots (*b* below and fig. 4-1 through 4-9) and flow and drawdown to wells (c below and fig. 4-10 through 4-22). Equations for slots are applicable to



FLOW

$$Q = \frac{kDx}{L}(H - h_e) \qquad (1)$$

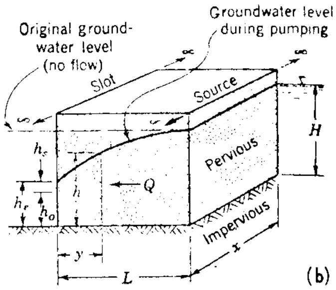
DRAWDOWN

AT ANY DISTANCE y FROM SLOT

$$H - h = \frac{Q}{kDx}(L - y) \qquad (2)$$

$$= \frac{L - y}{L}(H - h_e) \qquad (2a)$$

ARTESIAN FLOW



FLOW

$$Q = \frac{kx}{2L}(H^2 - h_o^2) \qquad (3)$$

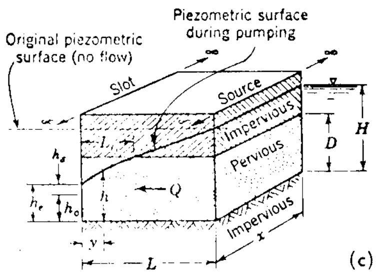
DRAWDOWN

AT ANY DISTANCE y FROM SLOT

$$H^2 - h^2 = \frac{L - y}{L}(H^2 - h_e^2) \qquad (4)$$

WHERE $h_e = h_o + h_s$ AND h_s IS OBTAINED FROM FIG. 4.2

GRAVITY FLOW



FLOW

$$Q = \frac{kx(D^2 - h_o^2)(2DH - D^2 - h_e^2)}{2L(D^2 - h_e^2)} \qquad (5)$$

WHERE $h_e = h_o + h_s$ AND h IS OBTAINED FROM* FIG. 4-2

DRAWDOWN

AT ANY DISTANCE y FROM SLOT

$$\text{FOR } y \leq L_G \quad H - h = H - \sqrt{\left\{D^2 - \left(\frac{L_G - y}{L_G}\right)[D^2 - (h_o + h_s)^2]\right\}} \qquad (6)$$

$$\text{FOR } y \geq L_G \quad H - h = H - \left[\left(\frac{H - D}{L - L_G}\right)(y - L_G) + D\right] \qquad (7)$$

WHERE L_G IS THE DISTANCE FROM THE SLOT TO THE POINT AT WHICH THE FLOW CHANGES FROM ARTESIAN TO GRAVITY, AND IS COMPUTED FROM

$$L_G = \frac{L[D^2 - (h_o + h_s)^2]}{2DH - D^2 - (h_o + h_s)^2} \qquad (8)$$

COMBINED ARTESIAN-GRAVITY FLOW

(Modified from "Foundation Engineering," G. A. Leonards, ed., 1962, McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

Figure 4-1. Flow and head for fully penetrating line slot; single-line source; artesian, gravity, and combined flows,

flow to trenches, French drains, and similar drainage systems. They may also be used where the drainage system consists of closely spaced wells or wellpoints. Assuming a well system equivalent to a slot usually simplifies the analysis; however, corrections must be made to consider that the drainage system consists of wells or wellpoints rather than the more efficient slot. These corrections are given with the well formulas discussed in *c* below. When the well system cannot be simulated with a slot, well equations must be used. The figures in which equations for flow to slots and wells appear are indexed in table 4-1. The equations for slots and wells do not consider the effects of hydraulic head losses H_w in wells or wellpoints; procedures for accounting for these effects are presented separately.

(3) ***Radius of influence R.*** Equations for flow to drainage systems from a circular seepage source are based on the assumption that the system is centered on an island of radius R. Generally, R is the radius of influence that is defined as the radius of a circle beyond which pumping of a dewatering system has no significant effect on the original groundwater level or piezometric surface. The value of R can be estimated

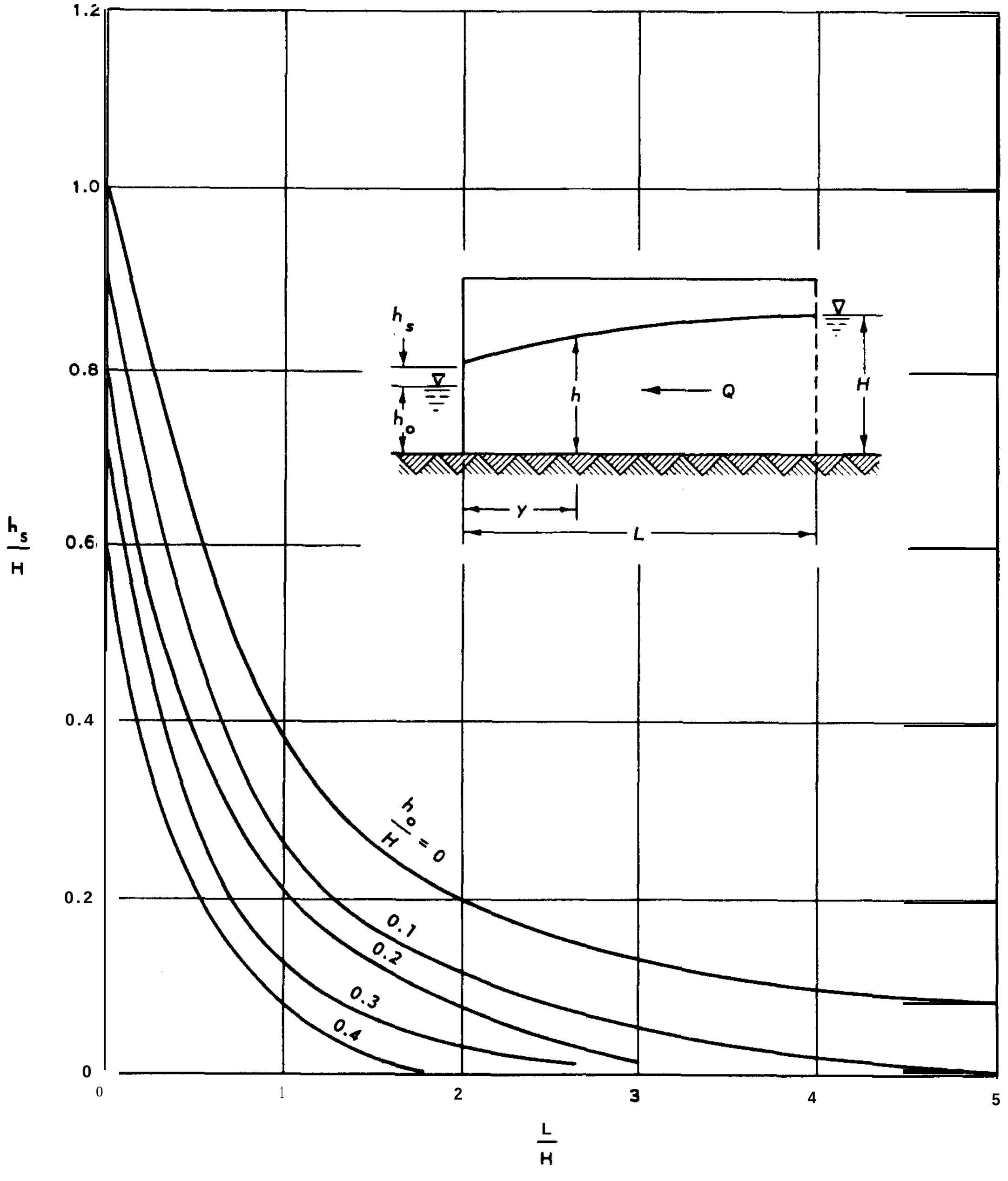


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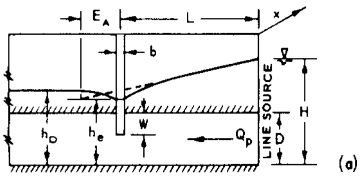
Figure 4-2. Height of free discharge surface h_s; gravity flow.



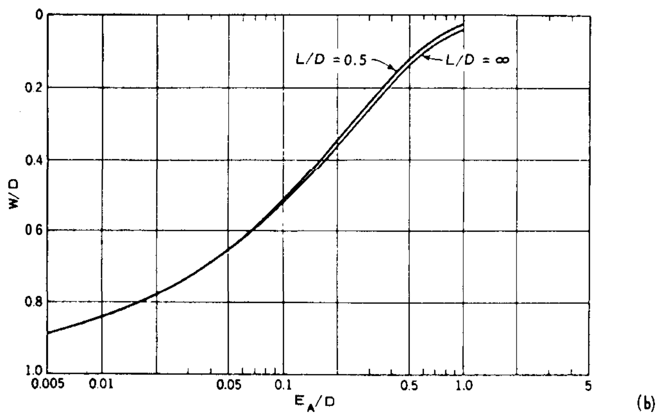
FLOW

$$Q_p = \frac{kDx(H - h_e)}{L + E_A} \qquad (1)$$

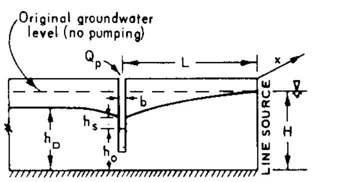
MAX RESIDUAL HEAD DOWNSTREAM OF SLOT

$$h_D = \frac{E_A(H - h_e)}{L + E_A} + h_e \qquad (2)$$

WHERE E_A IS AN ADDITIONAL LENGTH FACTOR OBTAINED FROM THE FIGURE BELOW



ARTESIAN FLOW



h_s IS OBTAINED FROM FIG. 4-2

(c)

FLOW

$$Q_p = \left(0.73 + 0.27\,\frac{H - h_o}{H}\right)\frac{kx}{2L}\left(H^2 - h_o^2\right) \qquad (3)$$

WHERE $L \geq 3H$

MAX RESIDUAL HEAD DOWNSTREAM OF SLOT

$$h_D = h_o\left[\frac{1.48}{L}(H - h_o) + 1\right] \qquad (4)$$

GRAVITY FLOW

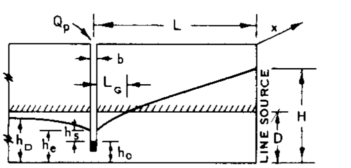
FLOW

$$Q_p = \frac{kDx(H - D)}{L - L_G} \qquad (5)$$

MAX RESIDUAL HEAD DOWNSTREAM OF SLOT+

$$h_D = h_o\left[\frac{1.48}{L_G}(D - h_o) + 1\right] \qquad (6)$$

PROVIDED $h_D \leq D; L_G \geq 3D$



h_s IS OBTAINED FROM FIG. 4-2

(d)

$$\text{WHERE } L_G = \frac{L\left(D^2 - h_o^2\right)\left(0.73 + 0.27\,\frac{D - h_o}{D}\right)}{2D(H - D) + \left(D^2 - h_o^2\right)\left(0.73 + 0.27\,\frac{D - h_o}{D}\right)} \qquad (7)$$

COMBINED ARTESIAN AND GRAVITY FLOWS

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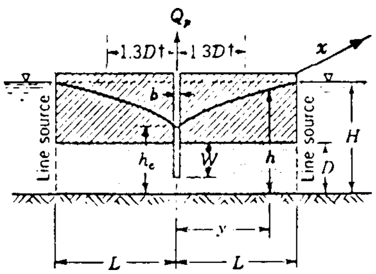
Figure 4-3. Flow and head for partially penetrating line slot; single-line source; artesian, gravity, and combined flows.

FULLY PENETRATING SLOT

THE FLOW TO A FULLY PENETRATING SLOT FROM TWO LINE SOURCES, BOTH OF INFINITE LENGTH (AND PARALLEL), IS THE SUM OF THE FLOW FROM EACH SOURCE, WITH REGARD TO THE APPROPRIATE FLOW BOUNDARY CONDITIONS, AS DETERMINED FROM THE FLOW EQUATIONS IN FIG. 4-1. LIKEWISE, THE DRAWDOWN FROM EACH SOURCE CAN BE COMPUTED FROM THE DRAWDOWN EQUATIONS IN FIG. 4-1 AS IF ONLY ONE SOURCE EXISTED.

PARTIALLY PENETRATING SLOT

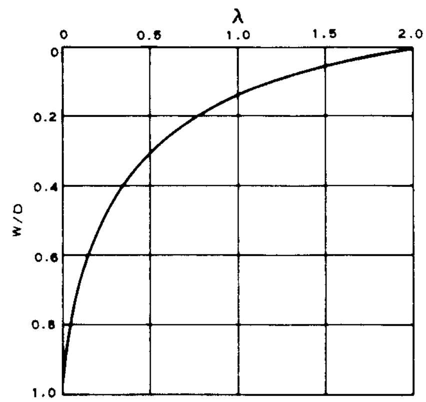
ARTESIAN FLOW



NOTE: WIDTH OF SLOT, b, ASSUMEO = 0.

t WITHIN THIS DISTANCE (1.3D) THE PIEZOMETRIC SURFACE IS NONLINEAR DUE TO CONVERGING FLOW.

(a)



(b)

FLOW

$$Q_p = \frac{2kDx(H - h_e)}{L + \lambda D} \qquad (1)$$

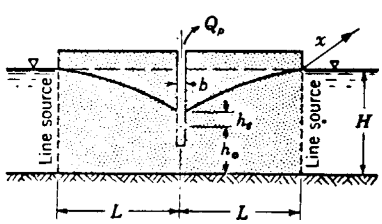
DRAWDOWN

AT ANY DISTANCE $y > 1.3D$ FROM SLOT.‡

$$H - h = H - \left[h_e + (H - h_e)\frac{y + \lambda D}{L + \lambda D}\right] \qquad (2)$$

‡ ORAWOOWN WHEN $y < 1.30$ CAN BE ESTIMATEO BY DRAWING A FREEHAND CURVE FROM h_e TANGENT TO THE SLOPE OF THE LINEAR PART AT $y = 1.3D$.

GRAVITY FLOW



(c)

FLOW

APPROXIMATELY, BUT SOMEWHAT LESS THAN, TWICE THAT COMPUTED FROM A SINGLE SOURCE, EQ 3, FIG. 4-3.

DRAWDOWN

APPROXIMATELY THAT COMPUTED FROM A SINGLE SOURCE, EQ 4, FIG. 4-1.

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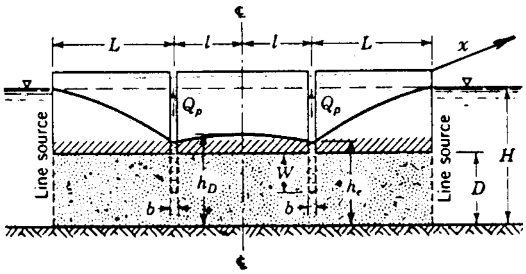
Figure 4-4. Flow and head for fully and partially penetrating line slot; two-line source; artesian and gravity flows.

A FREQUENTLY ENCOUNTERED DEWATERING SYSTEM IS ONE WITH TWO LINES OF PARTIALLY PENETRATING WELLPOINTS ALONG EACH SIDE OF A LONG EXCAVATION, WHERE THE FLOW CAN BE ASSUMED TO ORIGINATE FROM TWO EQUIDISTANT LINE SOURCES.



(a)

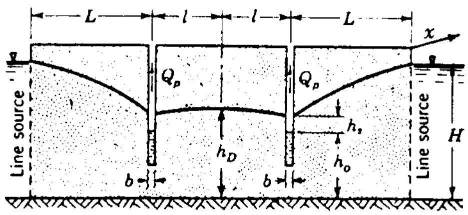
FLOW

FLOW FOR'EACH SLOT CAN BE ESTIMATED AS FOR ONE SLOT WITH ONE LINE SOURCE, EQ 1, FIG. 4-3.

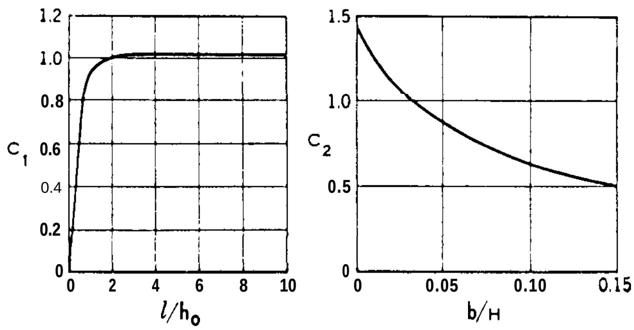
h_D†

VALUE OF h_D CAN BE ESTIMATED AS FOR ONE SLOT AND ONE LINE SOURCE, EQ 2, FIG. 4-3.

ARTESIAN FLOW



(b)



(c) (d)

FLOW

FLOW TO EACH SLOT APPROXIMATELY THAT ONE SLOT WITH ONE LINE SOURCE, EQ 3, FIG. 4-3.

h_D†

$$h_D = h_o\left[\frac{C_1 C_2}{L}(H - h_o) + 1\right] \tag{1}$$

WHERE C_1 AND C_2 ARE OBTAINED FROM FIG.(c) AND (d) ABOVE.

GRAVITY FLOW

† MAXIMUM RESIDUAL HEAO MIDWAY BETWEEN THE TWO SLOTS

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Figure 4-5. Flow and head (midway) for two partially penetrating slots; two-line source; artesian and gravity flows,

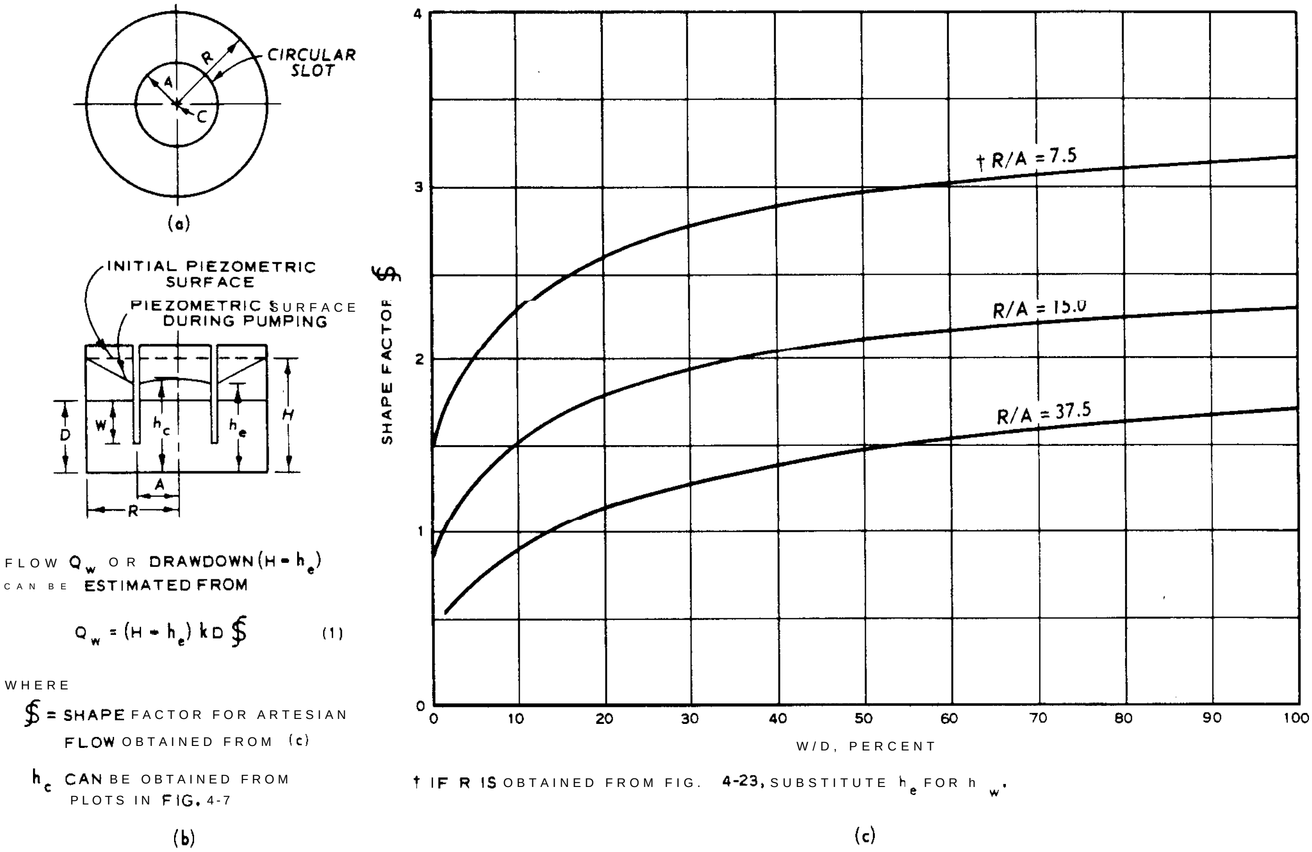

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Figure 4-6. Flow and head for fully andpartiullypenetratingcircular slots; circular source; *artesian flow*

from the equation and plots in figure 4-23. Where there is little or no recharge to an aquifer, the radius of influence will become greater with pumping time and with increased drawdown in the area being clewaterecl. Generally, R is greater for coarse, very pervious sands than for finer soils. If the value of R is large relative to the size of the excavation, a reasonably good approximation of R will serve adequately for clesign because flow and drawdown for such a condition are not especially sensitive to the actual value of R. As it is usually impossible to determine R accurately, the value should be select-d conservatively from pumping test data or, if necessary, from figure 4-23.

(4) *Wetted screen.* There should always be sufficient well and screen length below the requirecl drawdorn in a well in the formation being clewaterecl so that the design or requirecl pumping rate does not produce a gradient at the interface of the formation and the well filter (or screen) or at the screen and filter that starts to cause the flow to become turbulent. Therefore, the clesign of a clewatering system should always be checked to see that the well or wellpoints have ade-

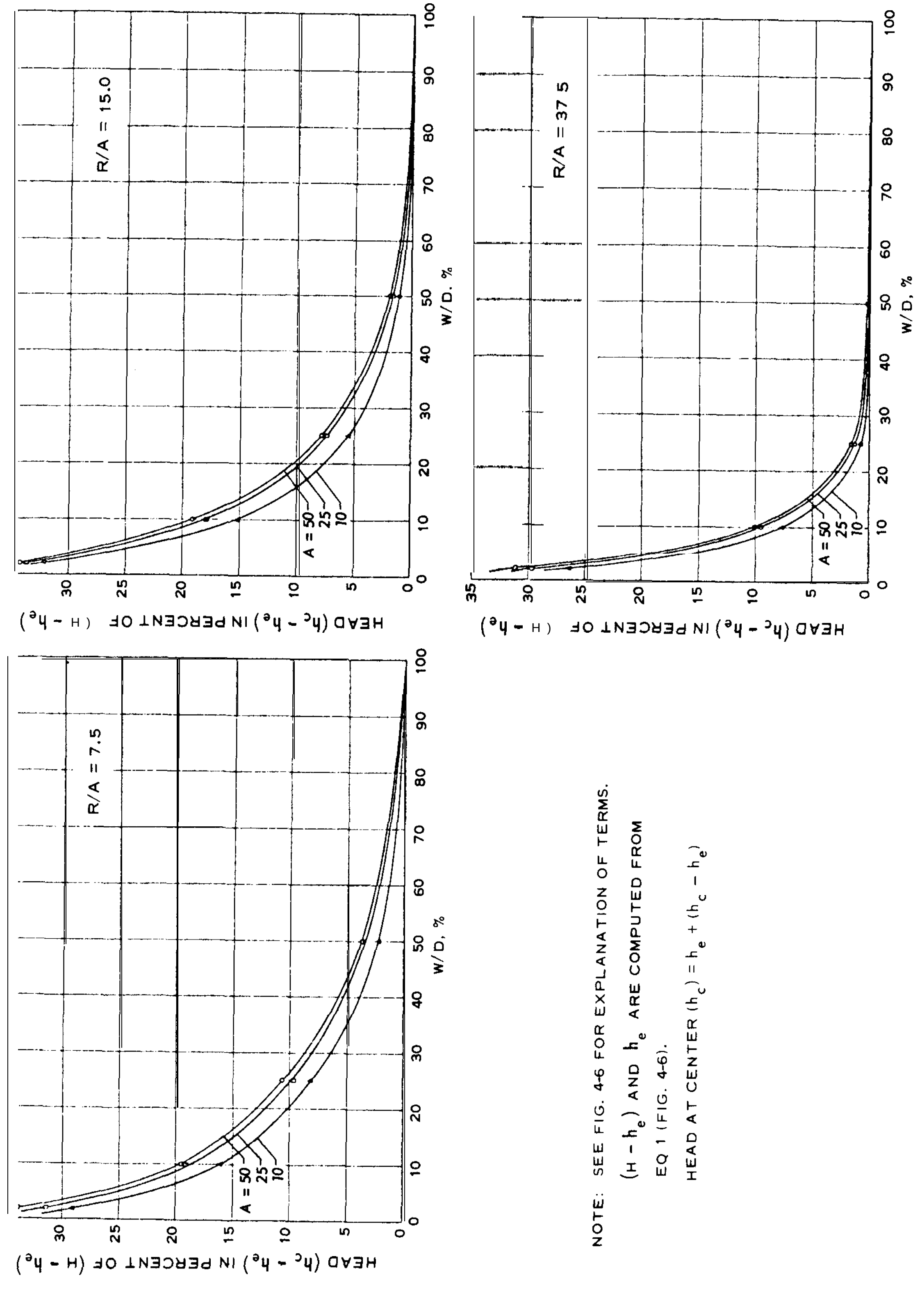

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Figure 4-7. Head at center of fully and partially penetrating circular slots; circular source; artesian flow,

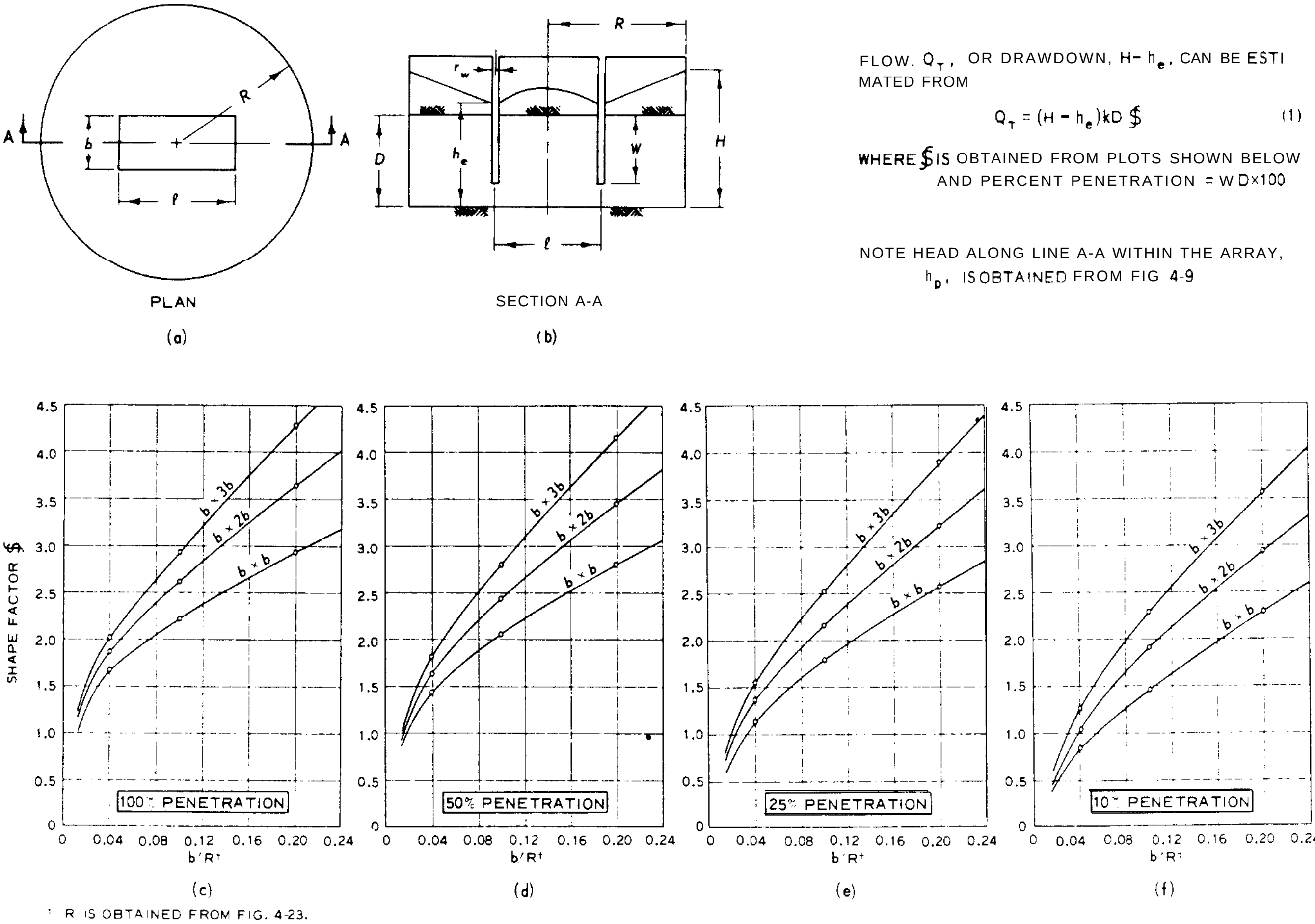

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Figure 4-8. Flow and drawdown at slot for fully and partially penetrating rectangular slots; circular source; artesian flow.

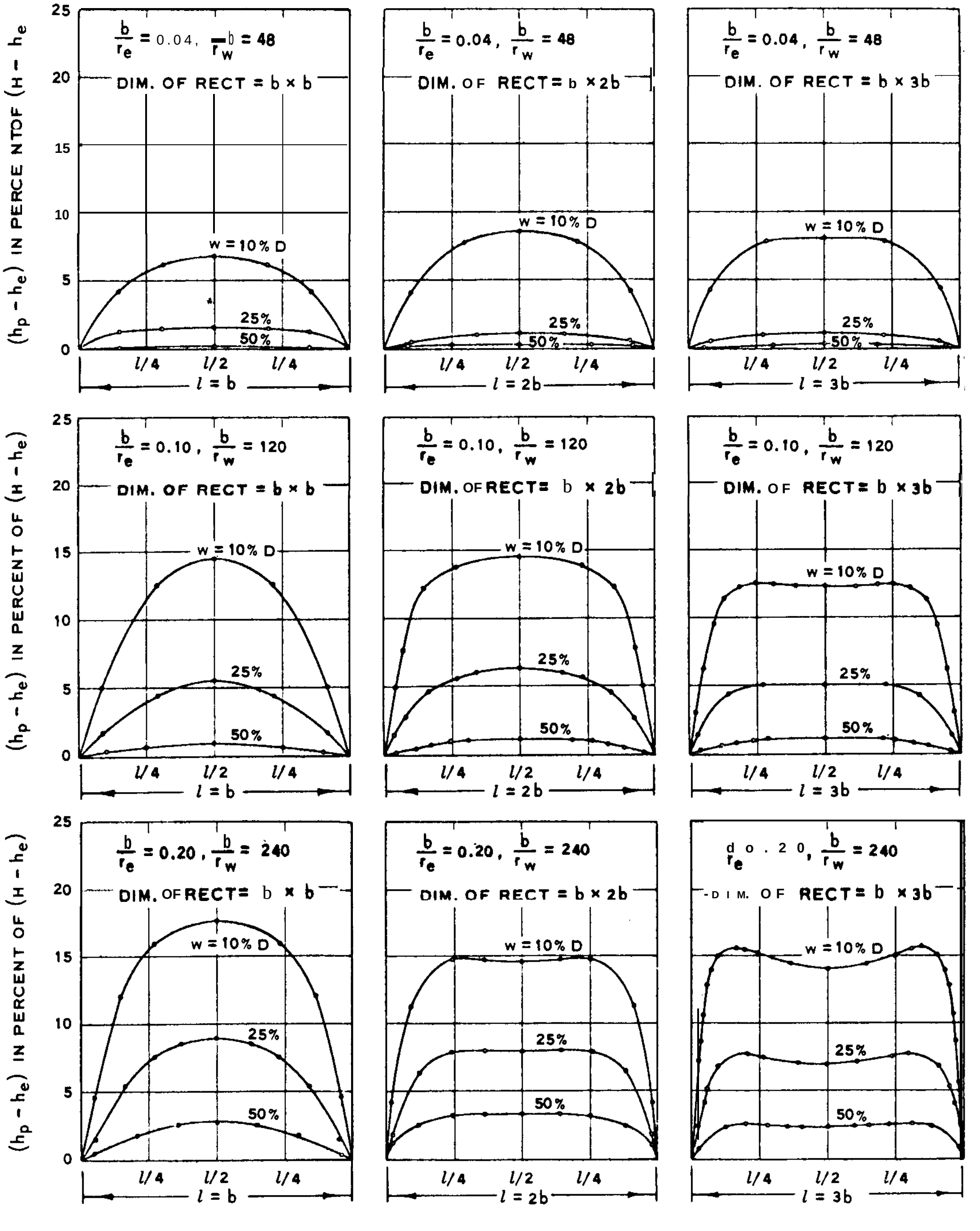
quate "wetted screen length h_{ws}" or submergence to pass the maximum computed flow. The limiting flow q_c into a filter or well screen is approximately equal to

$$q_c = \frac{2\pi r_w \sqrt{k}}{1.07} \times 7.48 \text{ gallons per minute per foot of filter or screen} \quad (4\text{-}1)$$

where

r_w = radius of filter or screen
k = coefficient of permeability of filter or aquifer sand, feet per minute

(5) *Hydraulic head loss H_w.* The equations in figures 4-1 through 4-22 do not consider hydraulic head losses that occur in the filter, screen, collector pipes, etc. These losses cannot be neglected, however, and must be accounted for separately. The hydraulic head loss through a filter and screen will depend upon the diameter of the screen, slot width, and opening per foot of screen, permeability and thickness of the filter; any clogging of the filter or screen by incrustation, drilling fluid, or bacteria; migration of soil or sand particles into the filter; and rate of flow per foot of screen. Graphs for estimating hydraulic head losses in pipes, wells, and screens are shown in figures 4-24 and 4-25.



NOTE: HEAD, h_p, ALONG LINE A-A IN FIG. 4-8a CAN BE OBTAINED FROM CURVES ABOVE.

$$h_p = h_e + (h_p - h_e)$$

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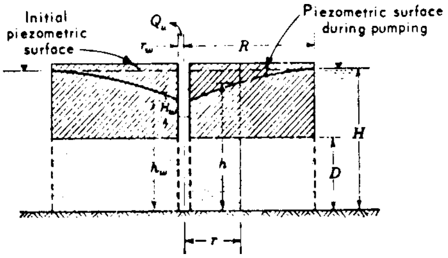
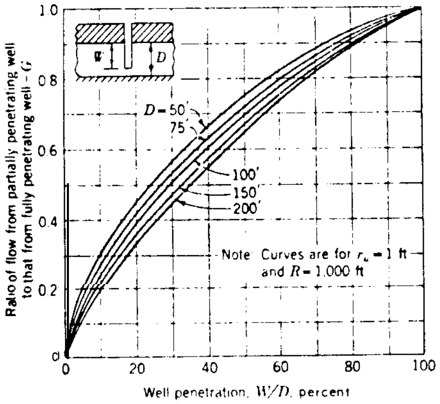
Figure 4-9. Head within a partially penetrating rectangular slot; circular source; artesian flow.



HYDRAULIC HEAD LOSS, H_w, IS OBTAINED FROM FIG. 4-24

RADIUS OF INFLUENCE, R, IS OBTAINED FROM FIG. 4-23

(a)



(b)

FULLY PENETRATING WELL

FLOW, Q_w

$$Q_w = \frac{2\pi kD(H-h)}{\ln(R/r)} \quad (1) \qquad \text{OR} \qquad Q_w = \frac{2\pi kD(H-h_w)}{\ln(R/r_w)} \quad (2)$$

DRAWDOWN, H - h

$$H-h = \frac{H-h_w}{\ln(R/r_w)} \ln\frac{R}{r} \quad (3)$$

PARTIALLY PENETRATING WELL

FLOW, Q_{wp}

$$Q_{wp} = \frac{2\pi kD(H-h_w)G}{\ln(R/r_w)} = Q_w - 100\% \times G \quad (4)$$

WHERE G IS EQUAL TO THE RATIO OF FLOW FROM A PARTIALLY PENETRATING WELL, Q_{wp}, TO THAT FOR A FULLY PENETRATING WELL FOR THE SAME DRAWDOWN, $H - h_w$, AT THE PERIPHERY OF THE WELLS.

APPROXIMATE VALUES OF G CAN BE COMPUTED FROM THE FORMULA:

$$G = \frac{W}{D}\left(1 + 7\sqrt{r_w/2W}\cos\frac{\pi W/D}{2}\right) \quad (5)$$

MORE EXACT VALUES CAN BE COMPUTED FROM THE FORMULA:

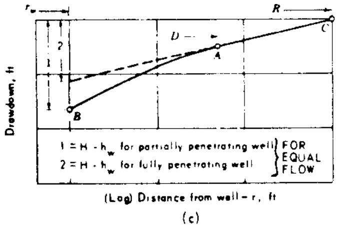
$$G = \frac{\ln R/r_w}{\frac{D}{2W}\left[2\ln\frac{4D}{r_w} - \ln\frac{\Gamma(0.875\,W/D)\,\Gamma(0.125\,W/D)}{\Gamma(1-0.875\,W/D)\,\Gamma(1-0.125\,W/D)}\right] - \ln\frac{4D}{R}} \quad (6)$$

WHERE Γ IS THE GAMMA FUNCTION; W = WELL PENETRATION.

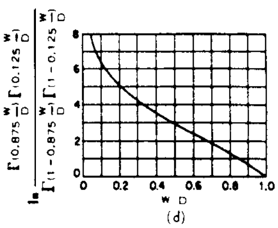
VALUES OF G FOR A TYPICAL LARGE-DIAMETER WELL (r_w = 1.0 FT) WITH A RADIUS OF INFLUENCE OF 1,000 FT ARE SHOWN IN (b) ABOVE.

DRAWDOWN, H - h

THE SHAPE OF THE DRAWDOWN CURVE IN THE VICINITY OF A PARTIALLY PENETRATING WELL CANNOT BE DETERMINED DIRECTLY FROM EQ 4 BUT CAN BE APPROXIMATED BY ASSUMING THE EFFECT OF WELL PENETRATION, W, IS INSIGNIFICANT BEYOND A DISTANCE, r, THAT IS GREATER THAN D. THE DRAWDOWN IS APPROXIMATED AS FOLLOWS:



(c)



(d)

1. COMPUTE Q_{wp} FROM EQ 4 FOR A GIVEN DRAWDOWN OF 1 ON (c).
2. COMPUTE $H - h_w$ FROM EQ 2 FOR A FULLY PENETRATING WELL FOR A DISCHARGE OF Q_{wp} (2 ON (c)).
3. PLOT DRAWDOWN FOR FULLY PENETRATING WELL VS (LOG) r AS SHOWN BY LINE AC IN (c).
4. DRAW A CURVED LINE FROM THE POINT (h_w, r_w) - POINT B IN ILLUSTRATION - FOR THE PARTIALLY PENETRATING WELL TO POINT A.

THE COMBINED CURVE, BAC, REPRESENTS AN APPROXIMATION OF THE DRAWDOWN CURVE FOR A PARTIALLY PENETRATING ARTESIAN WELL.

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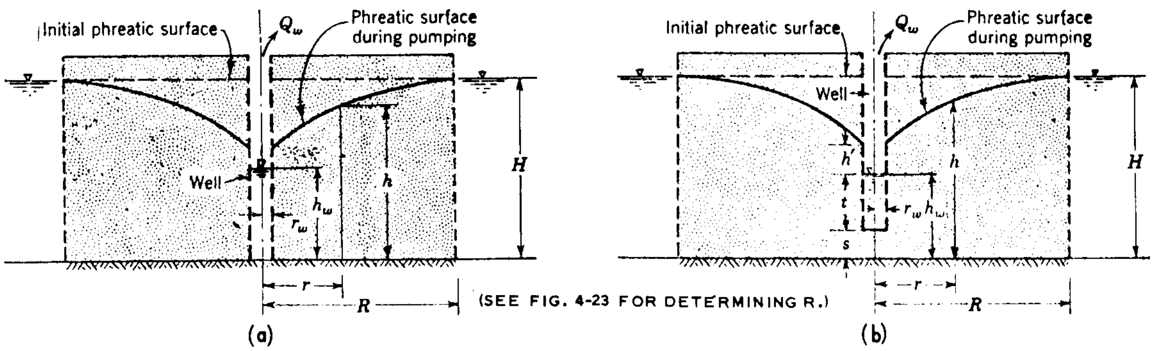
Figure 4-10. Flow and drawdown for fully and partially penetrating single wells; circular source; artesian flow.



FULLY PENETRATING WELL

FLOW, Q_w, OR DRAWDOWN, $H^2 - h^2$, NEGLECTING HEIGHT OF FREE DISCHARGE, h' (CONDITION (a)).

$$Q_w = \frac{\pi k(H^2 - h^2)}{\ln(R/r)} \quad (1) \qquad \text{OR} \qquad Q_w = \frac{\pi k\left(H^2 - h_w^2\right)}{\ln(R/r_w)} \quad (2)$$

FLOW, Q_w, TAKING h' INTO ACCOUNT (b) CAN BE ESTIMATED ACCURATELY FROM EQ 2 USING HEIGHT OF WATER, $h' + s$ ($s = 0$ FOR FULLY PENETRATING WELL), FOR THE TERM h_w.

FULLY OR PARTIALLY PENETRATING WELL

FLOW, Q_w, FOR ANY GRAVITY WELL WITH A CIRCULAR SOURCE

$$Q_w = \frac{\pi k\left[(H - s)^2 - t^2\right]}{\ln(R/r_w)}\left[1 + \left(0.30 + \frac{10r_w}{H}\right)\sin\frac{1.8s}{H}\right] \quad (3)$$

DRAWDOWN, $H - h$ OR $H^2 - h^2$, WHERE h' IS ACCOUNTED FOR (OBTAIN Q_w FROM EQ 3)

WHERE $r > 1.5H$,

$$H^2 - h^2 = \frac{Q_w}{\pi k}\ln\frac{R}{r} \quad (4)$$

WHERE $r < 1.5H$,

FOR $r/h > 1.5$, USE EQ 4

FOR $r/h < 1.5$,

$$H - h = \frac{Q_w P \ln(10R/H)}{\pi kH\left[1 - 0.8(s/H)^{1.5}\right]} \quad (5)$$

FOR $0.3 < r/h < 1.5$,

$$P = 0.13 \ln R/r \quad (6)$$

FOR $r/h < 0.3$,

$$P = \overline{C}_x + \Delta C \quad (7)$$

WHERE

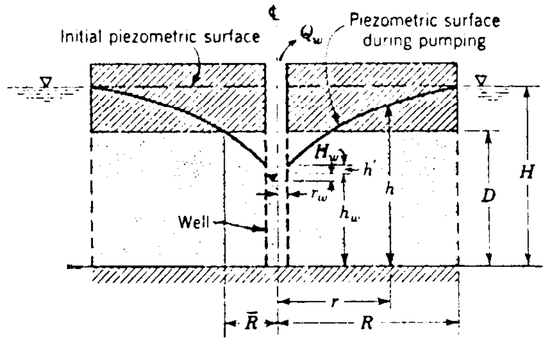
$$\overline{C}_x = 0.13 \ln\frac{R}{r} - 0.0123 \ln^2\frac{R}{10r} \quad (8)$$

AND

$$\Delta C = \frac{s}{h}\left[\left(\frac{1}{2.3}\ln\frac{R}{10r}\right)\left(1.2\frac{s}{H} - 0.48\right) + 0.113 \ln\frac{2.4H}{R}\ln\frac{R}{34r}\right] \quad (9)$$

(Modified from "Foundation Engineering," G. A. Leonards, ed., 1962, McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

Figure 4-11. Flow and drawdown for fully and partially penetrating single wells; circular source; gravity flow.



FLOW, Q_w, CAN BE COMPUTED FROM

$$Q_w = \frac{\pi k \left(2DH - D^2 - h_w^2\right)}{\ln\left(R/r_w\right)} \tag{1}$$

DRAWDOWN, H − h, CAN BE COMPUTED AT ANY DISTANCE FROM

$$H - h = H - \left(\frac{H - D}{\ln\left(R/r_w\right)} \ln \frac{r}{r_w} + \sqrt{D^2 - \frac{D^2 - h_w^2}{\ln\left(R/r_w\right)} \ln \frac{R}{r}} \right) \tag{2}$$

$\bar{R}$, DISTANCE FROM WELL AT WHICH FLOW CHANGES FROM GRAVITY TO ARTESIAN CAN BE COMPUTED FROM

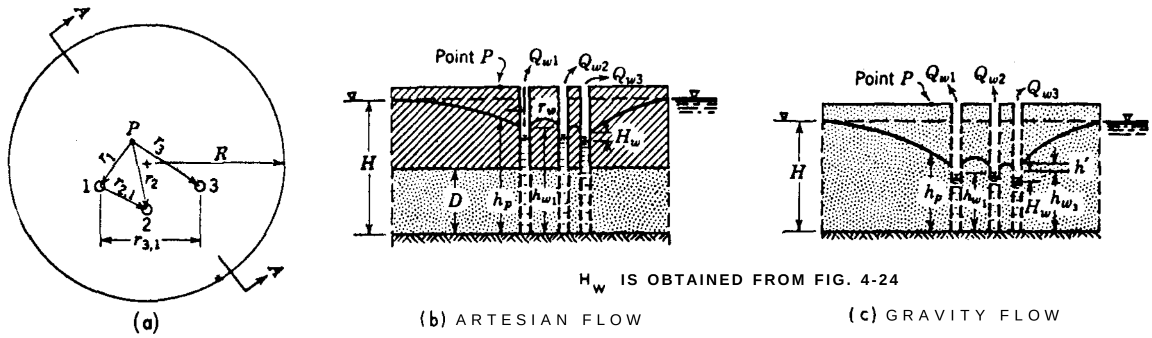
$$\ln \bar{R} = \frac{\left(D^2 - h_w^2\right) \ln R + 2D\left(H - D\right) \ln r_w}{2DH - D^2 - h_w^2} \tag{3}$$

R IS DETERMINED FROM FIG. 4-23.

EQUATIONS 1 AND 2 ARE BASED ON THE ASSUMPTION THAT THE HEAD h_w AT THE WELL IS AT THE SAME ELEVATION AS THE WATER SURFACE IN THE WELL. THIS WILL NOT BE TRUE WHERE THE DRAWDOWN IS RELATIVELY LARGE. IN THE LATTER CASE, THE HEAD AT AND IN THE CLOSE VICINITY OF THE WELL CAN BE COMPUTED FROM EQ 4 THROUGH 9 (FIG. 4-11). IN THESE EQUATIONS THE VALUE OF Q_w USED IS THAT COMPUTED FROM EQ 1, ASSUMING h_w EQUAL TO THE HEIGHT OF WATER IN THE WELL, AND THE VALUE OF $\bar{R}$ COMPUTED FROM EQ 3 IS USED IN LIEU OF R.

(Modified from "Foundation Engineering," G. A. Leonards, ed., 1962, McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)

Figure 4-12. Flow and dmwdown for fully penetmting single well; circular source; combined artesian and gravity flows.



H_w IS OBTAINED FROM FIG. 4-24

ARTESIAN FLOW

DRAWDOWN $(H - h_p)$ AT ANY POINT P

$$H - h_p = \frac{F}{2\pi k D} \tag{1}$$

WHERE

$$F\dagger = \sum_{i=1}^{i=n} Q_{wi} \ln\left(\frac{R_i}{r_i}\right) \tag{2}$$

AND Q_{wi} = FLOW FROM WELL i — R_i = RADIUS OF INFLUENCE FOR WELL i ‡

r_i = DISTANCE FROM WELL i TO POINT P — n = NUMBER OF WELLS IN THE ARRAY

GRAVITY FLOW

DRAWDOWN $(H^2 - h_p^2)$ AT ANY POINT P

$$H^2 - h_p^2 = \frac{F}{\pi k} \tag{3}$$

WHERE F IS COMPUTED FROM EQ 2

ARTESIAN OR GRAVITY FLOW

DRAWDOWN AT ANY WELL, j, FOR ARTESIAN OR GRAVITY FLOW CAN BE COMPUTED FROM EQ 1 OR 3 RESPECTIVELY, SUBSTITUTING F_w FOR F

WHERE

$$F_w = Q_{wj} \ln\left(\frac{R_j}{r_{wj}}\right) + \sum_{i=1}^{i=n-1} Q_{wi} \ln\left(\frac{R_i}{r_{ij}}\right) \tag{4}$$

AND Q_{wj} = FLOW FROM WELL j — r_{wj} = EFFECTIVE WELL RADIUS OF WELL j

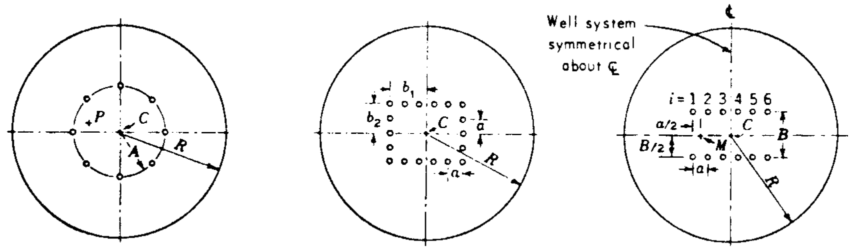
R_j = RADIUS OF INFLUENCE FOR WELL j — r_{ij} = DISTANCE FROM EACH WELL TO WELL j

† DRAWDOWN FACTORS, F, FOR SEVERAL COMMON WELL ARRAYS ARE GIVEN IN FIG. 4-14

‡ FOR RELATIVELY SMALL DEWATERING SYSTEMS AND WHERE NO UNUSUAL BOUNDARY CONDITIONS EXIST, THE RADIUS OF INFLUENCE FOR ALL WELLS CAN BE ASSUMED CONSTANT AS IN (a) ABOVE. SEE FIG. 4-23 FOR DETERMINING THE VALUE OF R.

(Modified *from "Foundation Engineering," G.A. Leonards, ed., 1962, McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.)*

Figure 4-13. Flow and dmwdown for fully penetrating multiple wells; circular source; artesian and gravity flows.



ARRAY 1 ARRAY 2 ARRAY 3

ALL WELLS ARE FULLY PENETRATING WITH A CIRCULAR SOURCE. THE FLOW, Q_w, FROM ALL WELLS IS EQUAL.

F_w = DRAWDOWN FACTOR FOR ANY WELL IN THE ARRAY. F_c = DRAWDOWN FACTOR FOR CENTER OF THE ARRAY. F_m = DRAWDOWN FACTOR AT POINT M IN ARRAY 3. $n, R, Q_w, h_p, h_w, r_w, r_i, r_{wj}$, r_{ij} ARE DEFINED IN FIG 4-13.

ARRAY 1. CIRCULAR ARRAY OF EQUALLY SPACED WELLS

$$F_w = Q_w \ln \frac{R^n}{n r_w A^{(n-1)}} \qquad (1) \qquad\qquad F_c = nQ_w \ln R/A \qquad (2)$$

WHERE A = DIMENSION SHOWN IN ARRAY 1 ABOVE.

DRAWDOWN AT POINTS P AND C FOR ARTESIAN FLOW CAN BE COMPUTED FROM

$$\text{DRAWDOWN} = (H - h_p) = \frac{(H-h_w)\left(n \ln R - \sum_{i=1}^{i=n} \ln r_i\right)}{\ln \frac{R^n}{n r_w A^{(n-1)}}} \qquad (3)$$

$$\text{DRAWDOWN} = (H - h_c) = \frac{(H-h_w) n \ln (R/A)}{\ln \frac{R^n}{n r_w A^{(n-1)}}} \qquad (4)$$

DRAWDOWN AT C FOR GRAVITY FLOW CAN BE COMPUTED FROM

$$(H - h_c) = H - \sqrt{H^2 - \frac{n(H^2 - h_w^2) \ln (R/A)}{\ln \frac{R^n}{n r_w A^{(n-1)}}}} \qquad (5)$$

ARRAY 2. RECTANGULAR ARRAY OF EQUALLY SPACED WELLS

F_w AND F MAY BE APPROXIMATED FROM EQ , AND 2, RESPECTIVELY, IF A_e IS SUBSTITUTED FOR A AN;

$$A_e = \frac{4}{\pi}\sqrt{b_1 b_2} \qquad (6)$$

F_w AND F_c CAN BE COMPUTED MORE EXACTLY FROM

$$F_w = Q_w \ln \frac{R}{r_{wj}} + \sum_{i=1}^{i=n-1} Q_w \ln \frac{R}{r_{ij}} \qquad (7) \qquad\qquad F_c = \sum_{i=1}^{i=n} Q_w \ln \frac{R}{r_i} \qquad (8)$$

ARRAY 3. TWO PARALLEL LINES OF EQUALLY SPACED WELLS

$$F_c = 4Q_w \sum_{i=1}^{i=n/4} \ln \frac{R}{1/2\sqrt{a^2(2i-1)^2 + B^2}} \qquad\qquad F_m = 2Q_w \sum_{i=1} \ln \frac{R}{1/2\sqrt{a^2(2i-3)^2 + B^2}}$$

WHERE i = WELL NUMBER AS SHOWN IN THE ARRAY ABOVE.

NOTE THAT THE LOCATION OF M IS MIDWAY BETWEEN THE TWO LINES OF WELLS AND CENTERED BETWEEN THE END TWO WELLS OF THE LINE. THIS POINT CORRESPONDS TO THE LOCATION OF THE MINIMUM DRAWDOWN WITHIN THE ARRAY.

VALUES DETERMINED FOR F_w, F_c, AND F_m ARE SUBSTITUTED FOR F IN EQ 1 AND 3 (FIG. 4-13) TO COMPUTE DRAWDOWN AT THE RESPECTIVE POINTS.

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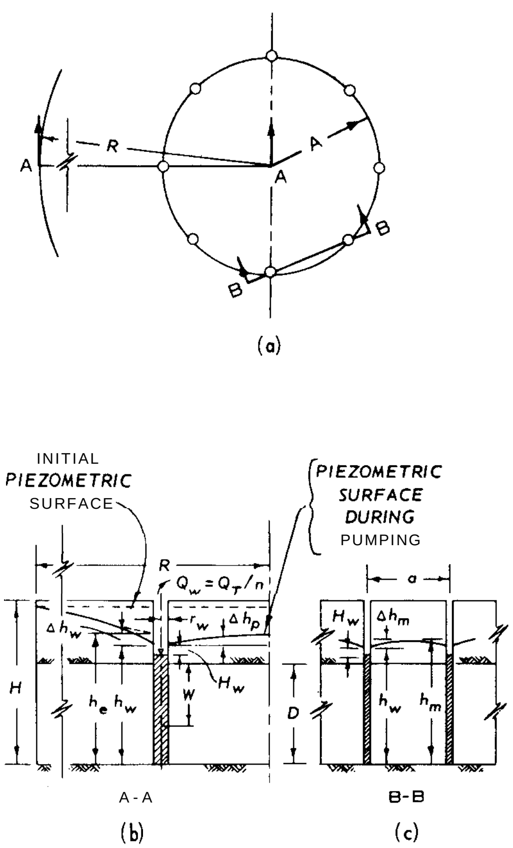
Figure 4-14. Drawdown factors for fully penetrating circular, rectangular, and two-line well arrays; circular source; artesian and gravity flows.

CIRCULAR ARRAY OF n NUMBER OF EQUALLY SPACED WELLS



HYDRAULIC HEAD LOSS IN WELL (H_w) IS OBTAINED FROM FIG. 4-24.

FULLY PENETRATING WELL

DRAWDOWN, $H - h_e$, PRODUCED BY PUMPING A FLOW OF Q_T FROM AN EQUIVALENT SLOT IS COMPUTED FROM EQ 1 (FIG. 4-6 OR 4-10) ($Q_T = nQ_w$)
n = NUMBER OF WELLS; Q_w = FLOW FROM A WELL)

HEAD LOSS DUE TO CONVERGING FLOW AT WELL

$$\Delta h_w = \frac{Q_w}{2\pi kD}\ln\frac{a}{2\pi r_w} = \frac{(H - h_e)\mathcal{S}}{2\pi n}\ln\frac{a}{2\pi r_w} \qquad (1)$$

TOTAL DRAWDOWN AT WELL (NEGLECTING HYDRAULIC HEAD LOSS, H_w)

$$H - h_w = H - h_e + \Delta h_w = \frac{Q_T}{kD}\left(\frac{1}{\mathcal{S}} + \frac{1}{2\pi n}\ln\frac{a}{2\pi r_w}\right) \qquad (2)$$

HEAD INCREASE MIDWAY BETWEEN WELLS

$$\Delta h_m = \frac{Q_w}{2\pi kD}\ln\frac{a}{\pi r_w} = \frac{(H - h_e)\mathcal{S}}{2\pi r_w}\ln\frac{a}{\pi r_w} \qquad (3)$$

DRAWDOWN MIDWAY BETWEEN WELLS

$$H - h_m = H - h_w - \Delta h_m = \frac{Q_T}{kD}\left[\frac{1}{S} - \frac{0.110}{n}\right] \qquad (4)$$

HEAD INCREASE IN CENTER OF A RING OF WELLS, Δh_D, IS EQUAL TO Δh_w AND CAN BE COMPUTED FROM EQ 1. DRAWDOWN AT THE CENTER OF THE RING OF WELLS, $H - h_D$, IS EQUAL TO $H - h_w - \Delta h_w$ OR $H - h_e$ AND, CONSEQUENTLY, CAN BE COMPUTED FROM EQ 1 (FIG. 4-6).

FOR EQ 1 THROUGH 4:

FLOWS FROM ALL WELLS ARE EQUAL
SHAPE FACTOR $\mathcal{S}$ IS OBTAINED FROM FIG 4-6c.
k = COEFFICIENT OF PERMEABILITY
ALL OTHER TERMS ARE EXPLAINED IN a, b, AND c

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Figure 4-15. *Flow and drawdown for fully penetrating circular well arrays; circular source; artesian flow*

(6) *Well or screen penetration W/D.*

(a) Most of the equations and graphs presented in this manual for flow and drawdown to slots or well systems were basically derived for fully penetrating drainage slots or wells. Equations and graphs for partially penetrating slots or wells are generally based on those for fully penetrating drainage systems modified by model studies and, in some instances, mathematical derivations. The amount or percent of screen penetration required for effective pressure reduction or interception of seepage depends upon many factors, such as thickness of the aquifer, distance to the effective source of seepage, well or wellpoint radius, stratification, required "wetted screen length," type and size of excavation, and whether or not the excavation penetrates alternating pervious and impervious strata or the bottom is underlain at a shallow depth by a less pervious stratum of soil or rock. Where a sizeable open excavation or tunnel is underlain by a fairly deep stratum of sand and wells are spaced rather widely, the well screens should penetrate at least 25 percent of the thickness of the aquifer to be dewatered below the

SEE FIG. 4-15, a, b, AND c FOR EXPLANATION OF TERMS NOT DEFINED IN THIS FIGURE.

DRAWDOWN, $H - h_e$, PRODUCED BY PUMPING A FLOW OF Q_T FROM AN EQUIVALENT SLOT, IS COMPUTED FROM EQ 1 (FIG. 4-6) FOR CIRCULAR SLOT AND EQ 1 (FIG. 4-8) FOR RECTANGULAR SLOT.

HEAD LOSS DUE TO CONVERGING FLOW AT WELL

$$\Delta h_w = \frac{Q_w \theta_a}{kD} = \frac{(H - h_e)\, \mathcal{S}\, \theta_a}{n} \tag{1}$$

TOTAL DRAWDOWN AT WELL (NEGLECTING H_w)

$$H - h_w = H - h_e + \Delta h_w = \frac{Q_T}{kD}\left(\frac{1}{\mathcal{S}} + \frac{\theta_a}{n}\right) \tag{2}$$

HEAD INCREASE MIDWAY BETWEEN WELLS

$$\Delta h_m = \frac{Q_w \theta_m}{kD} = \frac{(H - h_e)\, \mathcal{S}\, \theta_m}{n} \tag{3}$$

DRAWDOWN MIDWAY BETWEEN WELLS

$$H - h_m = H - h_w - \Delta h_m = \frac{Q_T}{kD}\left[\frac{1}{\mathcal{S}} + \frac{1}{n}(\theta_a - \theta_m)\right] \tag{4}$$

HEAD INCREASE IN CENTER OF A RING OF WELLS, Δh_D, IS EQUAL TO Δh_w AND CAN BE COMPUTED FROM EQ 1.

DRAWDOWN AT THE CENTER OF A RING OF WELLS, $H - h_D$, IS EQUAL TO $H - h_w - \Delta h_w$ OR $H - h_e$ AND, CONSEQUENTLY, CAN BE COMPUTED FROM EQ 1 (FIG. 4-6).

FOR EQ 1 THROUGH 4: $h_e = h_w + \Delta h_w$

FLDWS FROM ALL WELLS ARE EQUAL.

θ_a AND θ_m ARE DRAWDOWN FACTORS OBTAINED FROM FIG. 4-21 (a AND b, RESPECTIVELY).

$\mathcal{S}$ FROM FIG. 4-6 AND 4-0.

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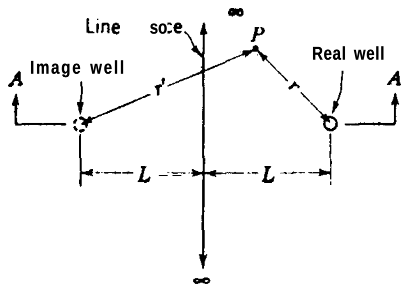
Figure 4-16. Flow and dmwdown for partially penetrating circular and rectangular well arrays; circular source; artesian flow.

bottom of the excavation and more preferably 50 to 100 percent. Where the aquifer(s) to be dewatered is stratified, the drainage slots or well screens should fully penetrate all the strata to be dewatered. If the bottom of an excavation in a pervious formation is underlain at a shallow depth by an impervious formation and the amount of “wetted screen length” available is limited, the drainage trench or well screen should penetrate to the top of the underlying less pervious stratum. The hydraulic head loss through various sixes and types of header or discharge pipe, and for certain well screens and (clean) filters, as determined from laboratory and field tests, are given in figures 4-24 and 4-25.

EQUATIONS FOR FLOW AND DRAWDOWN FOR A FULLY PENETRATING WELL WITH A LINE SOURCE OF INFINITE LENGTH WERE DEVELOPED UTILIZING THE METHOD OF IMAGE WELLS. THE IMAGE WELL IS CONSTRUCTED AS SHOWN IN (a) BELOW.



(a)

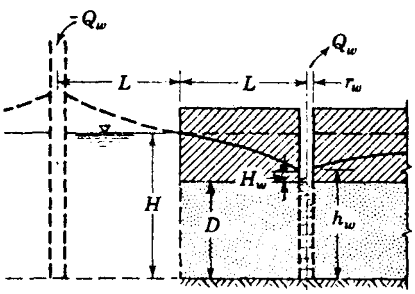
ARTESIAN FLOW

FLOW, Q_w

$$Q_w = \frac{2\pi k D (H - h_w)}{\ln (2L/r_w)} \qquad (1)$$

DRAWDOWN AT ANY POINT, P, LOCATED A DISTANCE, r, FROM THE WELL.

$$H - h = \frac{Q_w}{2\pi k D} \ln \left(\frac{r'}{r}\right) \qquad (2)$$



(b) ARTESIAN FLOW

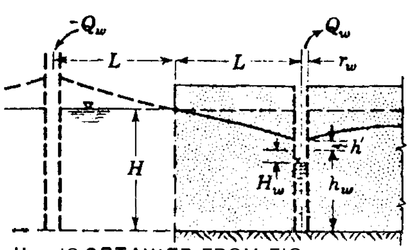
GRAVITY FLOW

FLOW, Q_w

$$Q_w = \frac{\pi k \left(H^2 - h_w^2\right)}{\ln (2L/r_w)} \qquad (3)$$

DRAWDOWN AT ANY POINT, P, LOCATED A DISTANCE, r, FROM THE WELL.

$$H^2 - h^2 = \frac{Q_w}{\pi k} \ln \frac{r'}{r} \qquad (4)$$



H_w IS OBTAINED FROM FIG. 4-24.

(c) GRAVITY FLOW

IN THE EQUATIONS ABOVE, THE DISTANCE TO THE LINE SOURCE MUST BE COMPARED TO THE CIRCULAR RADIUS OF INFLUENCE, R, FOR THE WELL. IF 2L IS GREATER THAN R, THE WELL WILL PERFORM AS IF SUPPLIED BY A CIRCULAR SOURCE OF SEEPAGE, AND SOLUTIONS FOR A LINE SOURCE OF SEEPAGE ARE NOT APPLICABLE.

SEE FIG. 4-23 FOR DETERMINING THE VALUE OF R.

SEE FIG. 4-24 FOR DETERMINING THE VALUE OF H_w.

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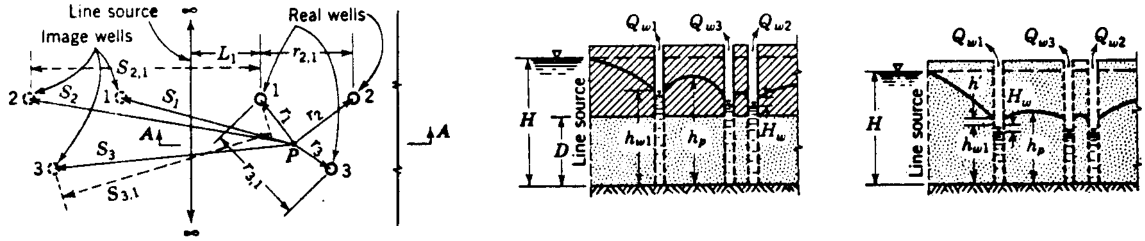
Figure 4-17. Flow and dmwdown for fully penetrating single well; line source; artesian and gravity flows.



(a) (b) ARTESIAN FLOW (c) GRAVITY FLOW

CONSTRUCTION OF THE IMAGE WELLS IS DISCUSSED IN THE TEXT OF PARAGRAPH 4-2

ARTESIAN FLOW

DRAWDOWN $(H - h_p)$ AT ANY POINT P

$$H - h_p = \frac{F'_p}{2\pi kD} \qquad (1)$$

WHERE

$$F'^{\dagger}_p = \sum_{i=1}^{i=n} Q_{wi} \ln \frac{S_i}{r_i} \qquad (2)$$

AND Q_{wi} = FLOW FROM WELL i

r_i = DISTANCE FROM WELL i TO POINT P

S_i = DISTANCE FROM IMAGE WELL i TO POINT P

n = NUMBER OF REAL WELLS

GRAVITY FLOW

DRAWDOWN $(H^2 - h_p^2)$ AT ANY POINT P

$$H^2 - h_p^2 = \frac{F'_p}{\pi k} \qquad (3)$$

WHERE $F'^{\dagger}_p$ IS COMPUTED FROM EQ 2.

ARTESIAN OR GRAVITY FLOW

DRAWDOWN AT ANY WELL, j, FOR ARTESIAN OR GRAVITY FLOW CAN BE COMPUTED FROM EQ 1 OR 3, RESPECTIVELY, SUBSTITUTING F'_w FOR F'_p

WHERE

$$F'_w = Q_{wj} \ln \frac{2L_j}{r_{wj}} + \sum_{i=2}^{i=n} Q_{wi} \ln \frac{S_{ij}}{r_{ij}} \qquad (4)$$

AND Q_{wj} = FLOW FROM WELL j

L_j = DISTANCE FROM LINE SOURCE TO WELL j

r_w = RADIUS OF WELL

Q_{wi} = FLOW FROM WELL i

S_{ij} = DISTANCE FROM IMAGE WELL i TO WELL j

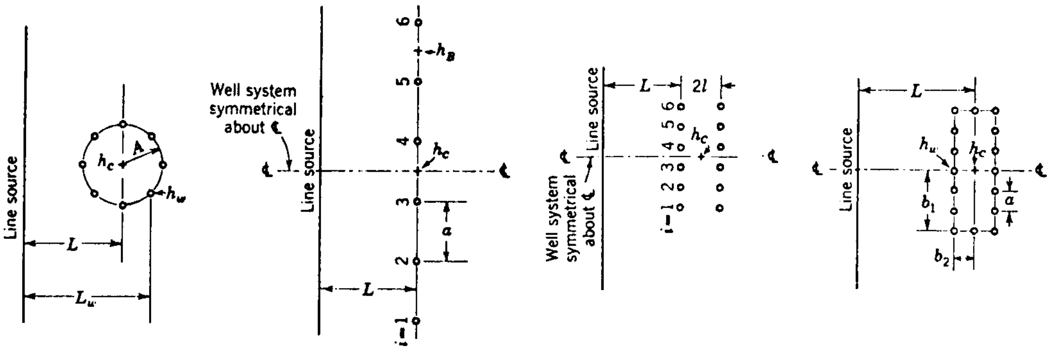
n = NUMBER OF REAL WELLS

r_{ij} = DISTANCE FROM EACH WELL TO WELL j

† DRAWDOWN FACTORS, F', FOR SEVERAL COMMON WELL ARRAYS ARE GIVEN IN FIG. 4-19

(Modified from "Foundation Engineering," G. A. Leonards, ed., 1962, McGraw-Hill Book Company, Used with permission of McGraw-Hill Book Company.)

Figure 4-18. Flow and dmwdown for fully penetrating multiple wells; line source; artesian and gravity flows.



ARRAY 1 | ARRAY 2 | ARRAY 3 | ARRAY 4

F'_c = DRAWDOWN FACTOR FOR CENTER OF ARRAY.
F'_w = DRAWDOWN FACTOR FOR ANY WELL OF ARRAY
F'_B = DRAWDOWN FACTOR FOR MIDWAY BETWEEN LAST TWO WELLS (ARRAY 2).

SEE EQ 1 AND 3 (FIG. 4-13) FOR DEFINITION OF F

VALUES DETERMINED FOR DRAWDOWN FACTORS ARE SUBSTITUTED INTO EQ 1 OR 3 (FIG. 4-18).
ALL WELLS ARE FULLY PENETRATING. FLOWS FROM ALL WELLS ARE EQUAL.
SEE FIG. 4-18 FOR EXPLANATION OF TERMS NOT DEFINED IN THIS FIGURE.

ARRAY 1 - CIRCULAR ARRAY OF EQUALLY SPACED WELLS

$$F'_c = \frac{Q_w}{2}\sum_{i=1}^{i=n} \ln\left[1 + 4\left(\frac{L}{A}\right)^2 - 4\left(\frac{L}{A}\right)\cos(i-1)\frac{2\pi}{n}\right] \tag{1}$$

IF $\frac{L}{A} \geq 2$

$$F'_c = Q_w\, n \ln\frac{2L}{A} \tag{2}$$

$$F'_w = Q_w\left(n \ln\frac{2L_w}{A} + \ln\frac{A}{nr_w}\right) \tag{3}$$

ARRAY 2 - SINGLE LINE OF EQUALLY SPACED WELLS

$$F'_c = 2Q_w \sum_{i=1}^{i=n/2} \ln\sqrt{1 + \left[\frac{2L}{(a/2)(n+1-2i)}\right]^2} \tag{4}$$

$$F'_B = Q_w \sum_{i=1}^{i=n} \ln\sqrt{1 + \left[\frac{2L}{(a/2)(2i-3)}\right]^2} \tag{5}$$

WHERE $n = \infty$ USE EQUATIONS GIVEN IN FIG. 4-20, 4-21, AND 4-22.

ARRAY 3 - TWO PARALLEL LINES OF EQUALLY SPACED WELLS

$$F'_c = 2Q_w \sum_{i=1}^{i=n/4}\left\{\ln\sqrt{1 + \left[\frac{2L + l}{(a/4)(n+2-4i)}\right]^2} + \ln\sqrt{1 + \left[\frac{2L + 3l}{(a/4)(n+2-4i)}\right]^2}\right\} \tag{6}$$

ARRAY 4 - RECTANGULAR ARRAY OF EQUALLY SPACED WELLS

APPROXIMATE METHOD. COMPUTE F'_w AND F'_c FROM EQ 1 OR 2 AND 3 RESPECTIVELY, WHERE A_e IS SUBSTITUTED FOR A AND

$$A_e = \frac{4}{\pi}\sqrt{b_1 b_2} \tag{7}$$

EXACT METHOD. COMPUTE F'_p AND F'_w FROM EQ 2 AND 4 (FIG. 4-18), RESPECTIVELY.

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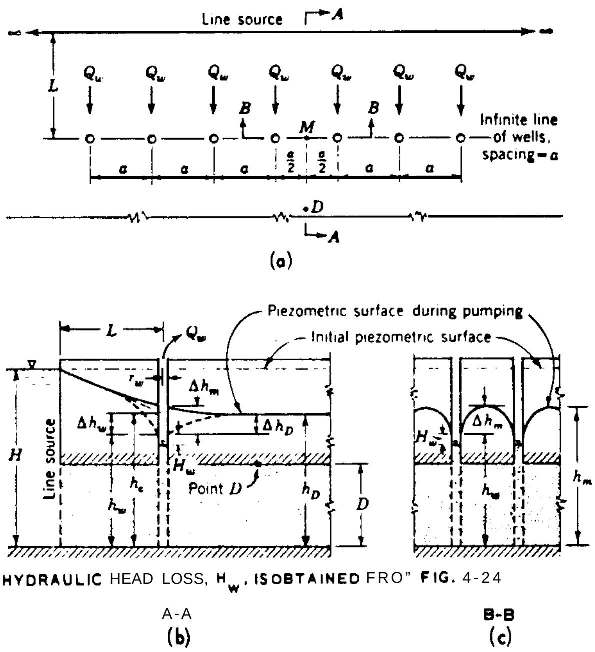
Figure 4-19. Drawdown factors for fully penetrating circular, line, two-line, and rectangular well arrays; line source; artesian and gravity flows.



DRAWDOWN, $H - h_e$, PRODUCED BY PUMPING Q_w FROM AN EQUIVALENT CONTINUOUS SLOT IS COMPUTED FROM $\frac{Q_w L}{kDa}$.

HEAD LOSS DUE TO CONVERGING FLOW AT WELL

$$\Delta h_w = \frac{Q_w}{2\pi kD} \ln \frac{a}{2\pi r_w} \tag{1}$$

TOTAL DRAWDOWN AT WELL (NEGLECTING HYDRAULIC HEAD LOSS, H_w)

$$H - h_w = H - h_e + \Delta h_w = \frac{Q_w L}{kDa} + \frac{Q_w}{2\pi kD} \ln \frac{a}{2\pi r_w} \tag{2}$$

HEAD INCREASE MIDWAY BETWEEN WELLS

$$\Delta h_m = \frac{Q_w}{2\pi kD} \ln \frac{a}{\pi r_w} \tag{3}$$

DRAWDOWN MIDWAY BETWEEN WELLS

$$H - h_m = H - h_w - \Delta h_m = \frac{Q_w L}{kDa} - 0.11 \frac{Q_w}{kD} \tag{4}$$

HEAD INCREASE Δh_D DOWNSTREAM OF WELLS IS EQUAL TO Δh_w, EQ 1.

DRAWDOWN $H - h_D$ DOWNSTREAM OF WELLS IS EQUAL TO $H - h_w - \Delta h_w$ OR $H - h_e$ AND, CONSEQUENTLY, CAN BE COMPUTED FROM EQ 1 (FIG. 4-1), WHERE $x = a$, AND $Q = Q_w$. $H - h_D$ CAN ALSO BE COMPUTED FROM

$$H - h_D = \frac{h_D - h_w}{(a/2\pi L)(\ln a/2\pi r_w)} \tag{5}$$

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Figure 4-20. Flow and drawdown for fully penetrating infinite line of wells; line source; artesian flow

SEE DRAWINGS IN FIG. 4-6 AND FIGURES (a) AND (b) BELOW FOR DEFINITIONS OF TERMS IN EQUATIONS.

DRAWDOWN, $H - h_e$, PRODUCED BY PUMPING Q_w FROM AN EQUIVALENT CONTINUOUS SLOT IS COMPUTED FROM EQ 1 (FIG. 4-3).

HEAD LOSS DUE TO CONVERGING FLOW AT WELL

$$\Delta h_w = \frac{Q_w \theta_a}{kD} \tag{1}$$

TOTAL DRAWDOWN AT WELL (NEGLECTING H_w)

$$H - h_w = H - h_e + \Delta h_w = \frac{Q_w}{kD}\left(\frac{L}{a} + \theta_a\right) \tag{2}$$

HEAD INCREASE MIDWAY BETWEEN WELLS

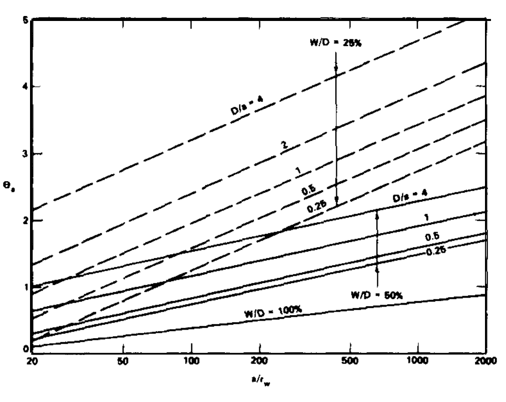
$$\Delta h_m = \frac{Q_w \theta_m}{kD} \tag{3}$$

DRAWDOWN MIDWAY BETWEEN WELLS

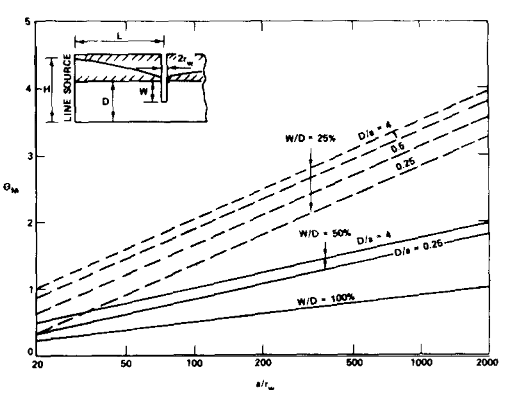
$$H - h_m = H - h_w - \Delta h_m = \frac{Q_w}{kD}\left(\frac{L}{a} + \theta_a - \theta_m\right) \tag{4}$$

HEAD INCREASE Δh_D DOWNSTREAM OF WELLS IS EQUAL TO Δh_w, EQ 1.

DRAWDOWN $H - h_D$ DOWNSTREAM OF WELLS IS EQUAL TO $H - h_w - \Delta h_w$ OR $H - h_e$ AND, CONSEQUENTLY, CAN BE COMPUTED FROM EQ 1 (FIG. 4-3).



(a)



(b)

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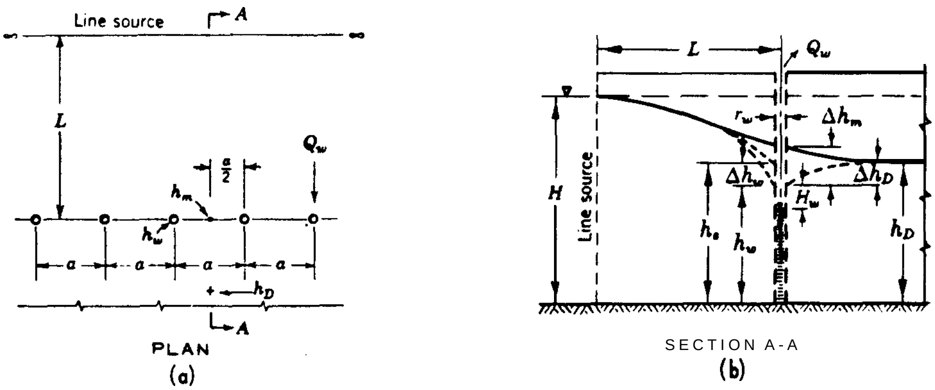
Figure 4-21. Flow and drawdown for fully and partially penetrating infinite line of wells; line source; artesian flow.



DRAWDOWN, $H^2 - h_e^2$, PRODUCED BY PUMPING Q_w FROM AN EQUIVALENT CONTINUOUS SLOT IS COMPUTED FROM $\frac{2QL}{k_a}$.

HEAD LOSS DUE TO CONVERGING FLOW AT WELL

$$h_e^2 - h_w^2 = \frac{Q_w}{\pi k} \ln \frac{a}{2\pi r_w} \tag{1}$$

TOTAL DRAWDOWN AT WELL

$$H^2 - h_w^2 = H^2 - h_e^2 = \frac{2Q_w L}{ka} + \frac{Q_w}{\pi k} \ln \frac{a}{2\pi r_w} \tag{2}$$

HEAD INCREASE MIDWAY BETWEEN WELLS

$$h_m^2 - h_w^2 = \frac{Q_w}{\pi k} \ln \frac{a}{\pi r_w} \tag{3}$$

DRAWDOWN MIDWAY BETWEEN WELLS

$$H^2 - h_m^2 = H^2 - h_w^2 - (h_m^2 - h_w^2) = \frac{Q_w}{k}\left(\frac{2L}{a} - \frac{\ln 2}{\pi}\right) \tag{4}$$

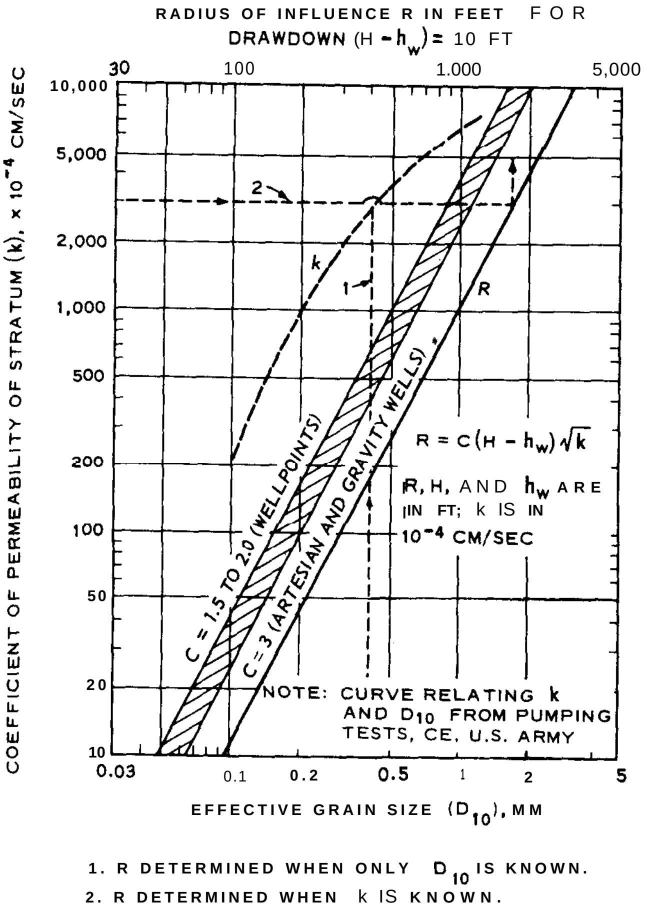
HEAD INCREASE Δh_D DOWNSTREAM OF WELLS IS EQUAL TO Δh_w (EQ 1.

DRAWDOWN $H^2 - h_D^2$ DOWNSTREAM OF WELLS IS EQUAL TO

$$H^2 - h_D^2 = \frac{h_D^2 - h_w^2}{\frac{a}{2\pi L} \ln \frac{a}{2\pi r_w}} \tag{5}$$

(Modified from "Foundation Engineering," G. A. Leonards, ed., 1962, McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company,)

Figure 4-22. Flow and dmwdown for fully penetrating infinite line of wells; line source; gmvity flow.



RADIUS OF INFLUENCE, R, CAN BE ESTIMATED FOR BOTH ARTESIAN AND GRAVITY FLOWS BY

$$R = C\,(H - h_w)\sqrt{k} \qquad (1)$$

WHERE R, H, AND h_w ARE DEFINED PREVIOUSLY AND EXPRESSED IN FEET. COEFFICIENT OF PERMEABILITY, k, IS EXPRESSED IN 10^{-4} CM/SEC.

AND C = 3 FOR ARTESIAN AND GRAVITY FLOWS TO A WELL.

C = 1.5 TO 2.0 FOR A SINGLE LINE OF WELLPOINTS.

THE VALUE OF R FOR $(H - h_w) = 10$ FT CAN BE DETERMINED FROM THE PLOT HEREIN WHEN EITHER THE D_{10} SIZE OR PERMEABILITY OF THE MATERIAL IS KNOWN. THE VALUE OF R WHEN $(H - h_w) \neq 10$ CAN BE DETERMINED BY MULTIPLYING THE R VALUE OBTAINED FROM THE PLOT BY THE RATIO OF THE ACTUAL VALUE OF $(H - h_w)$ TO 10 FT.

A DISCUSSION ON THE DETERMINATION OF R FROM EQ 1 AND PUMPING TESTS IS CONTAINED IN PARAGRAPH 4-2a(3) OF THE TEXT.

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Figure 4-23. Approximate radius of influence R.

(*b*) Head losses in the screened section of a well H_s are calculated from figure 4-24b. This head loss is based on equal inflow per unit of screen surface and turbulent flow inside the well and is equivalent to the entire well flow passing through one-half the screen length. Other head losses can be determined directly from figure 4-24. Hydraulic head loss within a wellpoint system can be estimated from figure 4-25. As stated in *a*(4) above, flow into a well can be impeded by the lack of "wetted screen length," in addition to hydraulic head losses in the filter or through the screens and/or chemical or mechanical clogging of the aquifer and filter.

b. Flow to a drainage slot.

(1) *Line drainage slots.* Equations presented in figures 4-1 through 4-5 can be used to compute flow and head produced by pumping either a single or a double continuous slot of infinite length. These equations assume that the source of seepage and the drainage slot are infinite in length and parallel and that seepage enters the pervious stratum from a vertical line source. In actuality, the slot will be of finite length, the flow at the ends of the slot for a distance of about L/2 (where L equals distance between slot and source) will be greater, and the drawdown will be less than for the central portion of the slot. Flow to the ends of a fully penetrating slot can be estimated, if necessary, from flow-net analyses subsequently presented.

Table 4-1. Index to Figures for Flow, Head, or Drawdown Equations for Given Corrections

Index	Assumed Source of Seepage	Drainage System	Type of Flow	Penetration	Figure
Flow to a slot	Line	Line slot	A, G, C	F	4-1, 4-2
	Line	Line slot	A; G; C	P	4-2, 4-3
	Tvo-line	Line slot	A, G	P, F	4-4
	Two-line	Two-line slots	A, G	P	4-5
	Circular	Circular slots	A	P, F	4-6, 4-7
	Circular	Rectangular slots	A	P, F	4-8, 4-9
Flow to wells	Circular	Single vell	A	P, F	4-10
	Circular	Single well	G	P, F	4-11
	Circular	Single vell	C	F	4-12
	Circular	Multiple wells	A, G	F	4-13
	Circular	Circular, rectangular, and tvo-line arrays	A, G	F	4-14
	Circular	Circular array	A	F	4-15
	Circular	Circular and rectangular array	A	P	4-16
	Single line	Single vell	A, G	F	4-17
	Single line	Multiple wells	A, G	F	4-18
	Single line	Circular, line, two-line, and rectangular arrays	A, G	F	4-19
	Single line	Infinite line	A	F	4-20
	Single line	Infinite line	A	P, F	4-21
	Single line	Infinite line	G	F	4-22
Other	Approximate radius of influence				4-23
	Hydraulic head loss in a vell				4-24
	Hydraulic head loss in various wellpoints				4-25
	Equivalent length of straight pipe for various fittings				4-26
	Shape factors for wells of various penetrations centered inside a circular source				4-27
	Flow and drawdown for slots from flow-net analyses				4-28
	Flow and drawdown for wells from flow-net analyses				4-29
	Diagrammatic layout of electrical analogy model				4-30

Note: A = artesian flow; G = gravity flow; C = combined artesian-gravity flow; F = fully penetrating; P = partially penetrating.

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